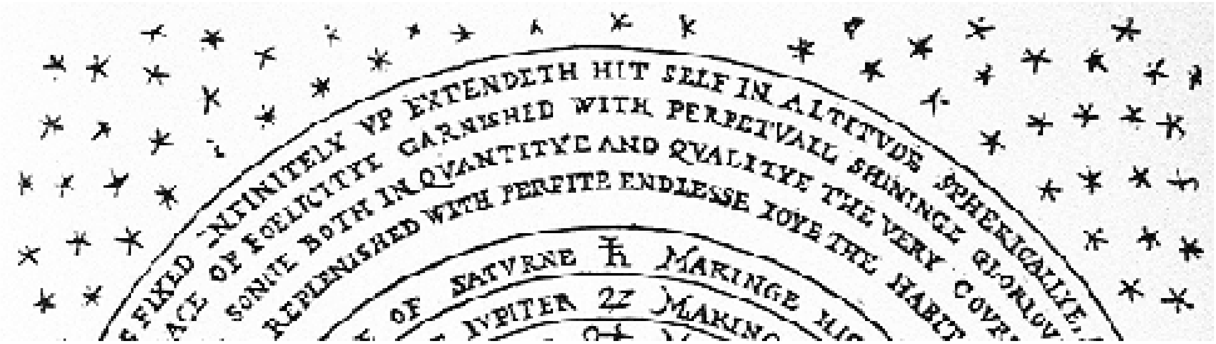


PHY1033C/HIS3931/IDH 3931 : Discovering Physics:

The Universe and Humanity's Place in It

Fall 2016

Prof. Peter Hirschfeld, Physics

Announcements

- Reading this week: Gregory, Chapter 6

Observations of the moon, The satellites of Jupiter, Galileo's Theory of the Tides, Excerpts from *The Dialogues*

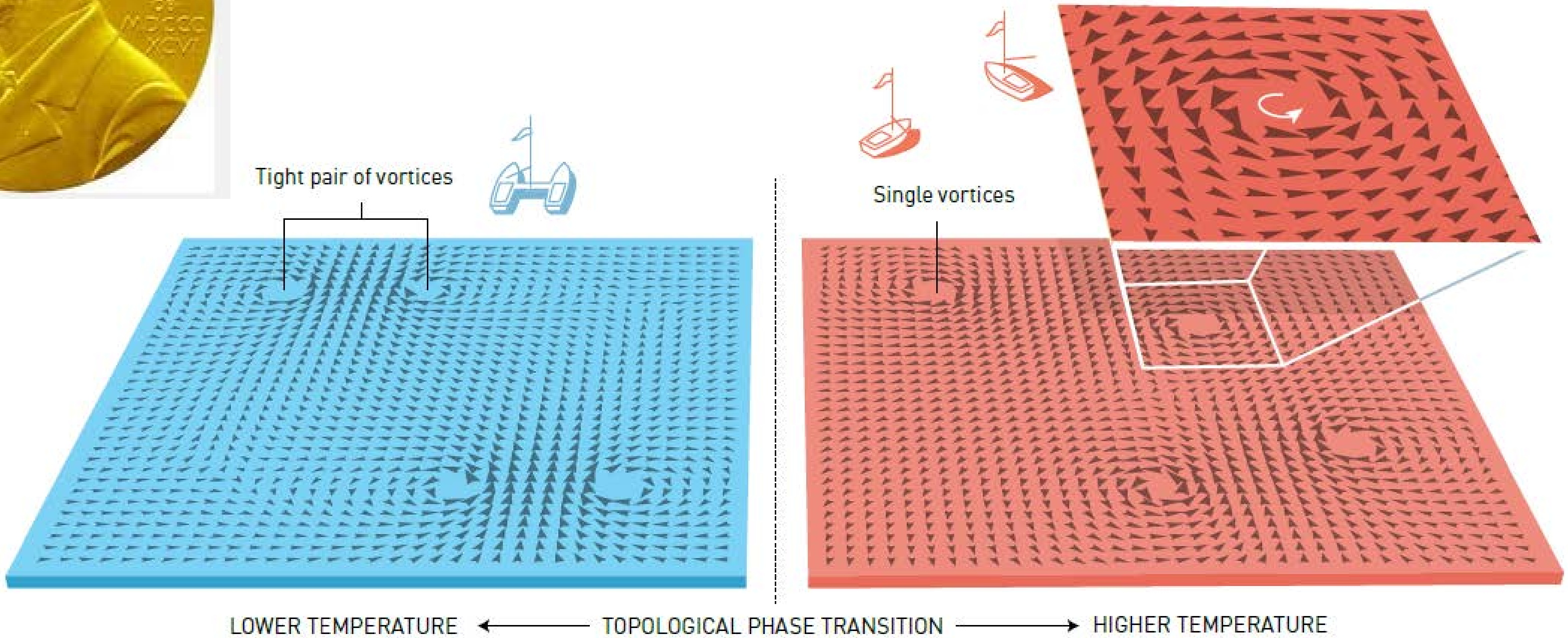
- HW 4 due today, HW3 solutions and HW5 posted

  Note HW5 may take longer than usual!!!!
- Practice midterm posted on course "Tests" page
- Test announcements

Midterm exam

- In class Thursday, Oct. 13
- Covers all material up through end of Week 7 (10/6)
- Bring: ID, scratch paper (calculator optional)
- Format: 30% mult. choice 40% short answer 30% essay (choice of 2)
- Review 1 (Ariel B): NPB east lounge 6pm Monday 10/10
- Review 2: (Peter H): NPB 2205 5:30pm Wednesday 10/12
- 1 side paper "cheat sheet" (handwritten) allowed

Nobel prize in physics 2016



To David Thouless, Duncan Haldane and Michael Kosterlitz
"for the theoretical discoveries of topological phase transitions and topological phases of matter."

Johannes Kepler
1571 -1630

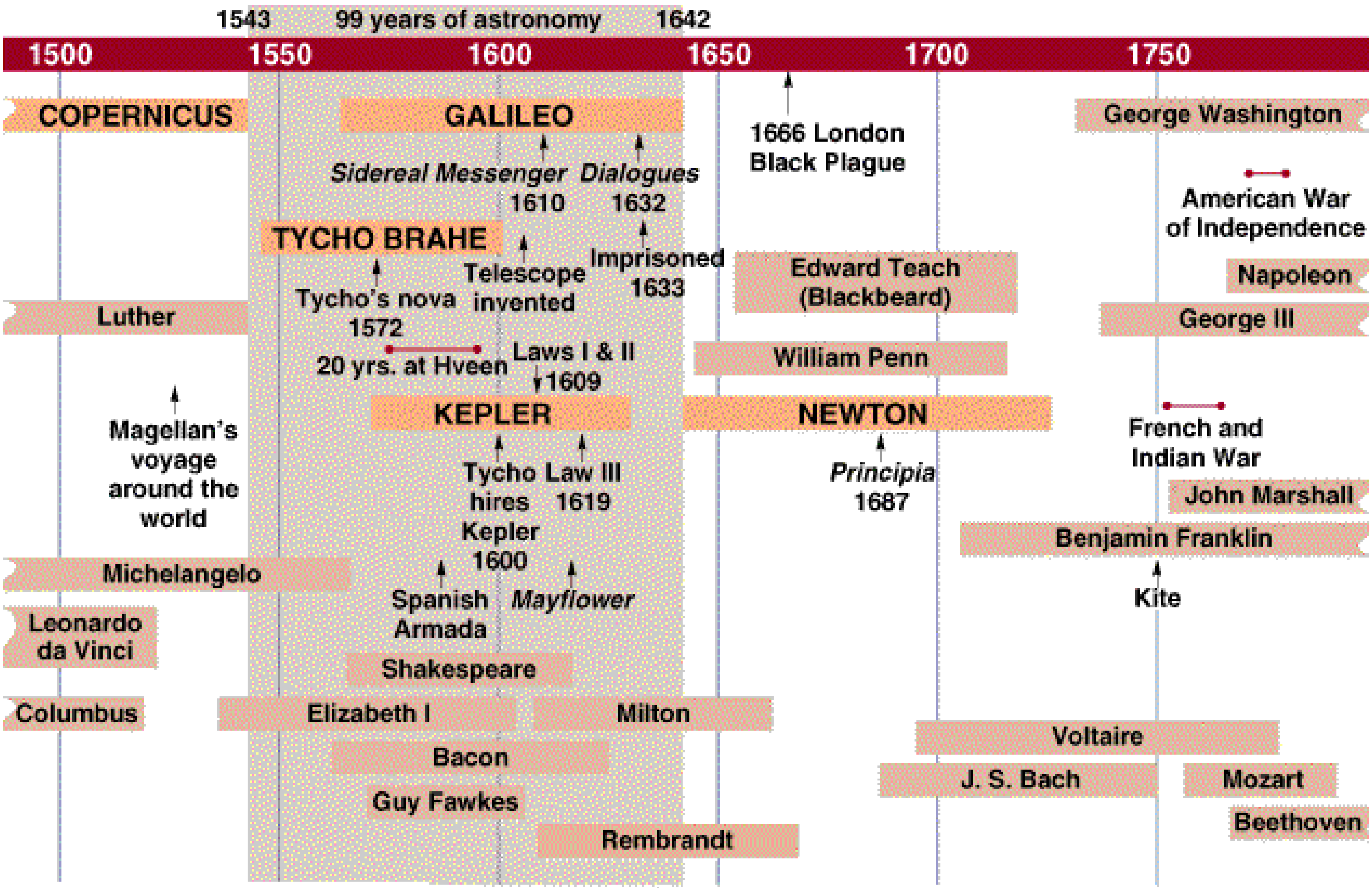
Last time

- Kepler: looked for mathematical beauty in the universe as way of knowing God
- Early work: orbits of planets correspond to nested regular ("platonic") solids – explains # planets, orbit spacing – sort of.
- Later: he works with Tycho's data, develops 3 laws:
  1) Planets move in *ellipses* with sun at 1 focus
  2) planets sweep out equal areas in equal times*
  3) relationship of orbital period to radius: $T^2 \propto R^3$

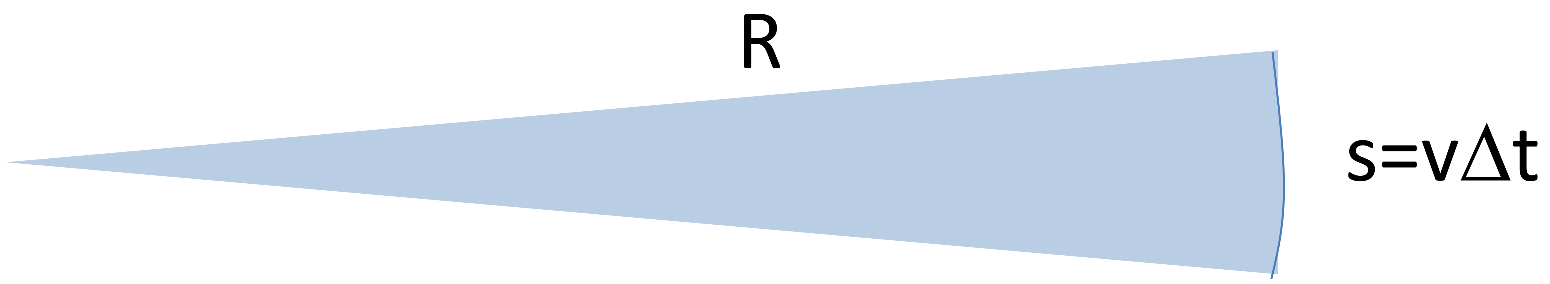
* 2nd law related to "conservation of angular momentum" – similar to figure skater

http://www.huffingtonpost.com/2015/02/15/kepler-432b-exoplanet-extreme-seasons_n_6672378.html

Timeline


1543
99 years of astronomy
1642
1500
1550
1600
1650
1700
1750
COPERNICUS
GALILEO
Sidereal Messenger 1610
Dialogues 1632
1666 London Black Plague
George Washington
American War of Independence
TYCHO BRAHE
Tycho's nova 1572
Telescope invented
Imprisoned 1633
Edward Teach (Blackbeard)
Napoleon
Luther
George III
20 yrs. at Hveen
Laws I & II 1609
William Penn
Magellan's voyage around the world
KEPLER
NEWTON
French and Indian War
Tycho hires Kepler 1600
Law III 1619
Principia 1687
John Marshall
Benjamin Franklin
Michelangelo
Spanish Armada
Mayflower
Kite
Leonardo da Vinci
Shakespeare
Columbus
Elizabeth I
Milton
Voltaire
Bacon
J. S. Bach
Mozart
Guy Fawkes
Beethoven
Rembrandt

Slice of Earth's orbit swept out in time Δt



Area $\approx Rs = Rv\Delta t$

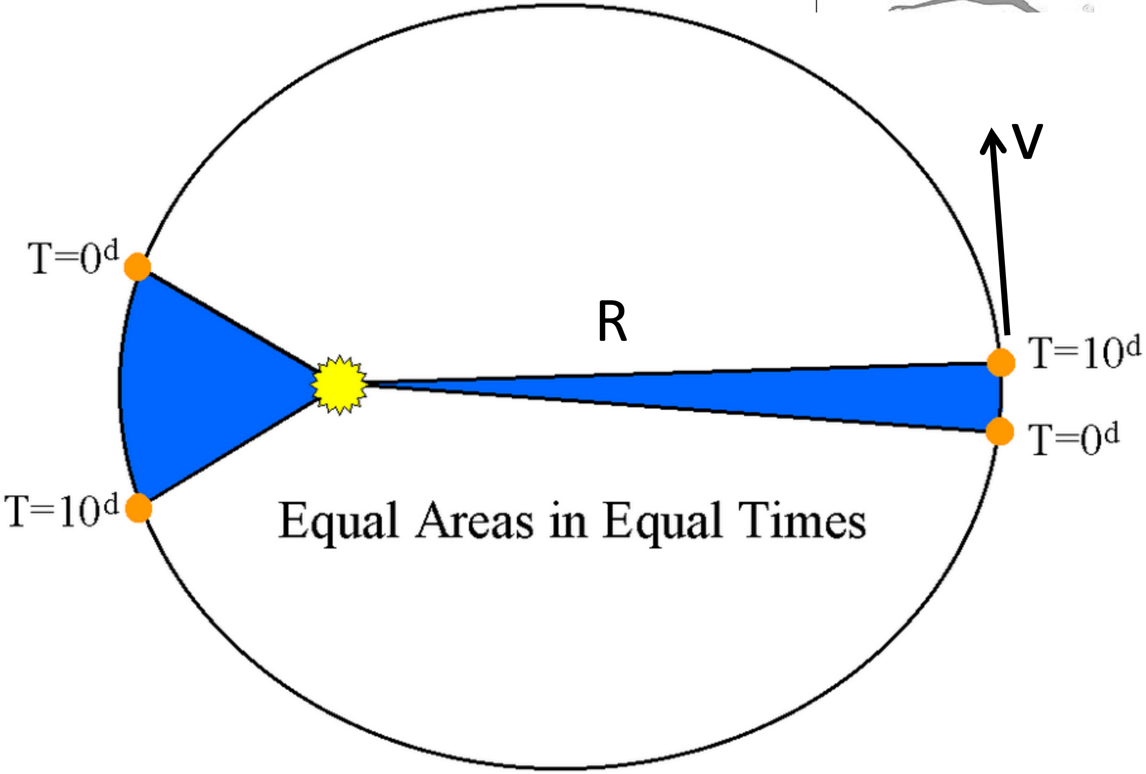
Rv const.$\Rightarrow$ equal areas in equal times!

Let's check!

Angular momentum conservation

- R (mv) = const

p= mv momentum



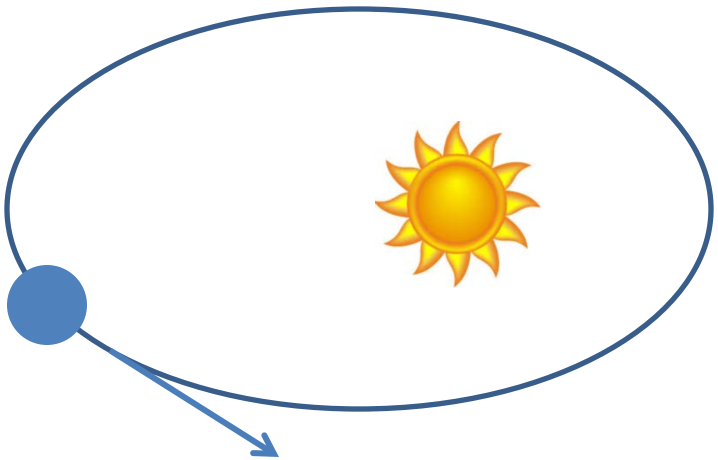
Kepler's 3rd law

(HW 5)

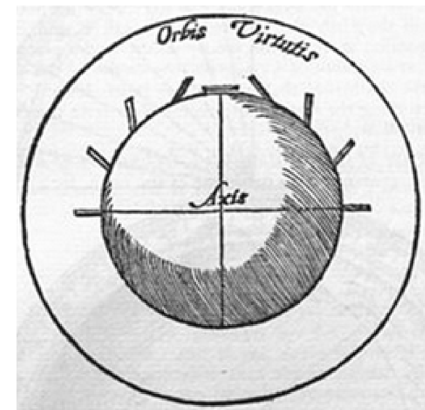
1. (2 pts.) Check Kepler's 3rd law against the currently measured planetary orbit radii and periods. First use the data given in the table below, and fill in all last two columns for the planets. Now make a graph of R^3 vs T^2, and determine the slope of the line that best fits the data (Hint: before starting to graph, check what the largest (R^3, T^2) will be—this will determine the upper right corner of your graph.). Please use graph paper (you can print some here). Using this, predict the orbital period of a new planet that you are told was discovered to be 3300x10^6 km from the sun, and fill in the last 3 blank spaces.

Planet	Average orbit radius R (10^6 km)	Orbital period T (Earth days)	R^3	T^2
Mercury	58	88		
Venus	108	224		
Earth	149	365		
Mars	228	687		
Jupiter	778	4333		
Saturn	1426	10,759		
Unknown planet	3300			

Kepler:
1st to pose question of what *causes* planetary motions



What's making it move around the sun?



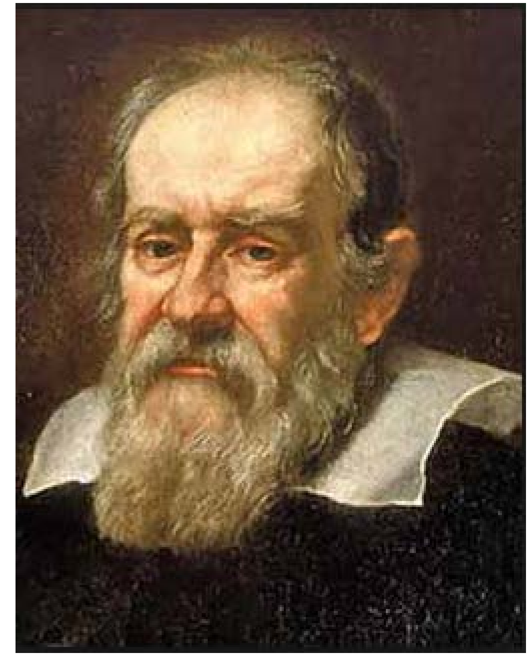
Wm. Gilbert, 1600: the Earth is a magnet

Kepler: maybe the Sun exerts a magnetic pull or push on the Earth!

Kepler tried all sorts of shapes to account for Mars’ orbit, & finally settled on

1. An ellipse, with a sun at one focus
2. A perfect circle, with the sun off center
3. A perfect square
4. A regular icosahedron
5. An epicycle on deferent

Galileo Galilei
1564-1642



- Studied medicine at university in Pisa, but real interest was math

- Impressed Jesuit mathematician, was able to obtain teaching position at Pisa

- Early indications of Copernicanism, e.g. letter to Kepler; however did not avow publicly

- Unlike many other philosophers, liked to write in vernacular rather than latin – astute political sense

Quote from papa (Vincenzo Galilei, musician)

"It appears to me that those who rely simply on the weight of authority to prove any assertion, without searching out the arguments to support it, act absurdly. I wish to question freely and to answer freely without any sort of adulation. That well becomes any who are sincere in the search for truth."

Galileo and falling bodies: Aristotle must be wrong--a "thought experiment"

Consider two bodies, one weighing twice as much as the other. Aristotle would say 1 would fall twice as fast as 2, $v_1=2v_2$

Galileo: tie the two together. Light one should retard heavy one, since it wants to fall more slowly. So speed of total is $v_{tot}<v_1=2v_2$

But one can equally well regard the two as a composite object weight which should fall with three times the speed of the light body, so $v_{tot}=3v_2$ *Internal contradiction*

Galileo and falling bodies

- Story from biographer: G dropped balls of different weight from tower, found they hit bottom at same time

- Galileo rejected Aristotle, but believed (early years) that all objects would accelerate until they reached *terminal velocity* characteristic of specific material

Not quite true!

Flash forward reminder: terminal velocity

$a = 9.8\ m/s^2$

Right after jumping: v increases 9.8 m/s per sec. *Accelerated motion*!

$v \approx 120$mph

After a few seconds of free fall, air resistance increases with speed to the point where it cancels gravity: *uniform motion* at $v_{terminal}$

Brian Cox demonstrates that bowling ball & feather fall at same rate in a (near) vacuum

https://www.youtube.com/watch?v=E43-CfukEgs&feature=share

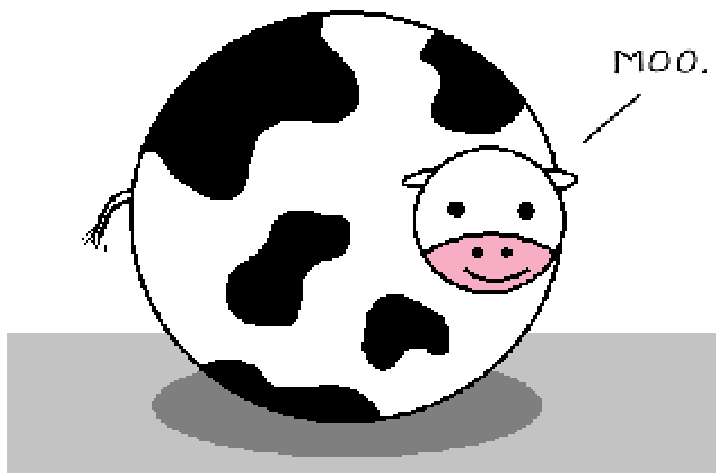
Although Galileo probably didn't do the leaning tower expt. as legend would have it, he would have loved to do the expt. with the vacuum pump, since he developed the technique of *idealization* in physics

What would happen if I removed the air?
What would happen if I removed friction?

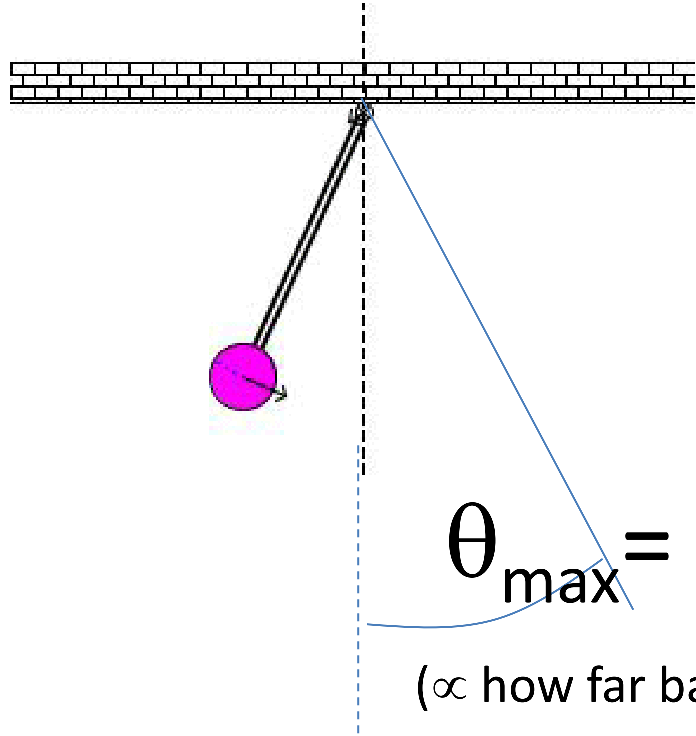
Physicists' metaphor: spherical cow

The farmer's cow wasn't giving milk; he
had tri . So
he calle id she
would visited
the far solution.
The ph nd began,
"Consi

Yes, that was the punch line!



Galileo's Pendulum



Pisa cathedral

θ_{max} = "amplitude"

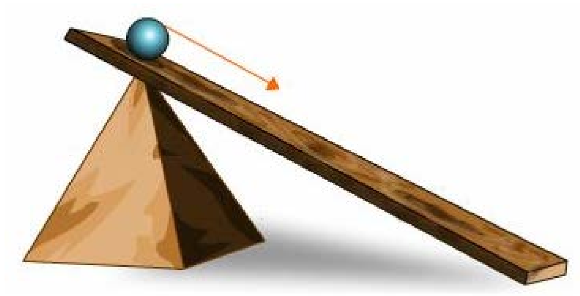
($\propto$ how far back you pull the weight initially)

Galileo noticed that the time for one oscillation, the period T, does *not* depend on the amplitude, for small amplitude oscillations. He measured T with his pulse, and in fact proposed a pendulum as a way to measure pulses in hospitals!

You'll verify this in the lab today!

Galileo's expts. with inclined planes

- enabled him to slow down motion to observe it better
- convinced him that mathematics could be applied to earthly as well as celestial realm



Galileo demonstrates inclined plane to Giovanni de Medici
Giuseppe Bezuoli, 1841

Galileo showed that height of falling body varied as (time to ground)^2, or $y \propto t^2$

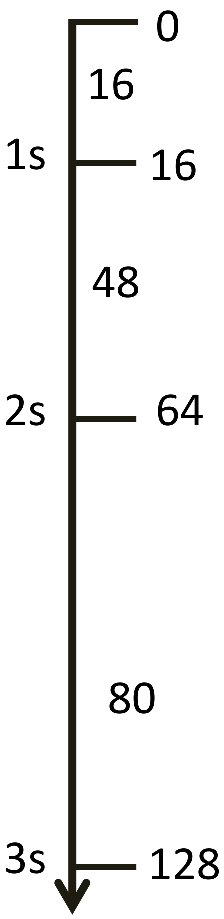
Galileo: vertical distance traversed in equal times increased in accordance with sequence of odd numbers:

e.g *ratio* 1 : 3 : 5 : 7 distances fallen in 1,2,3,4 sec

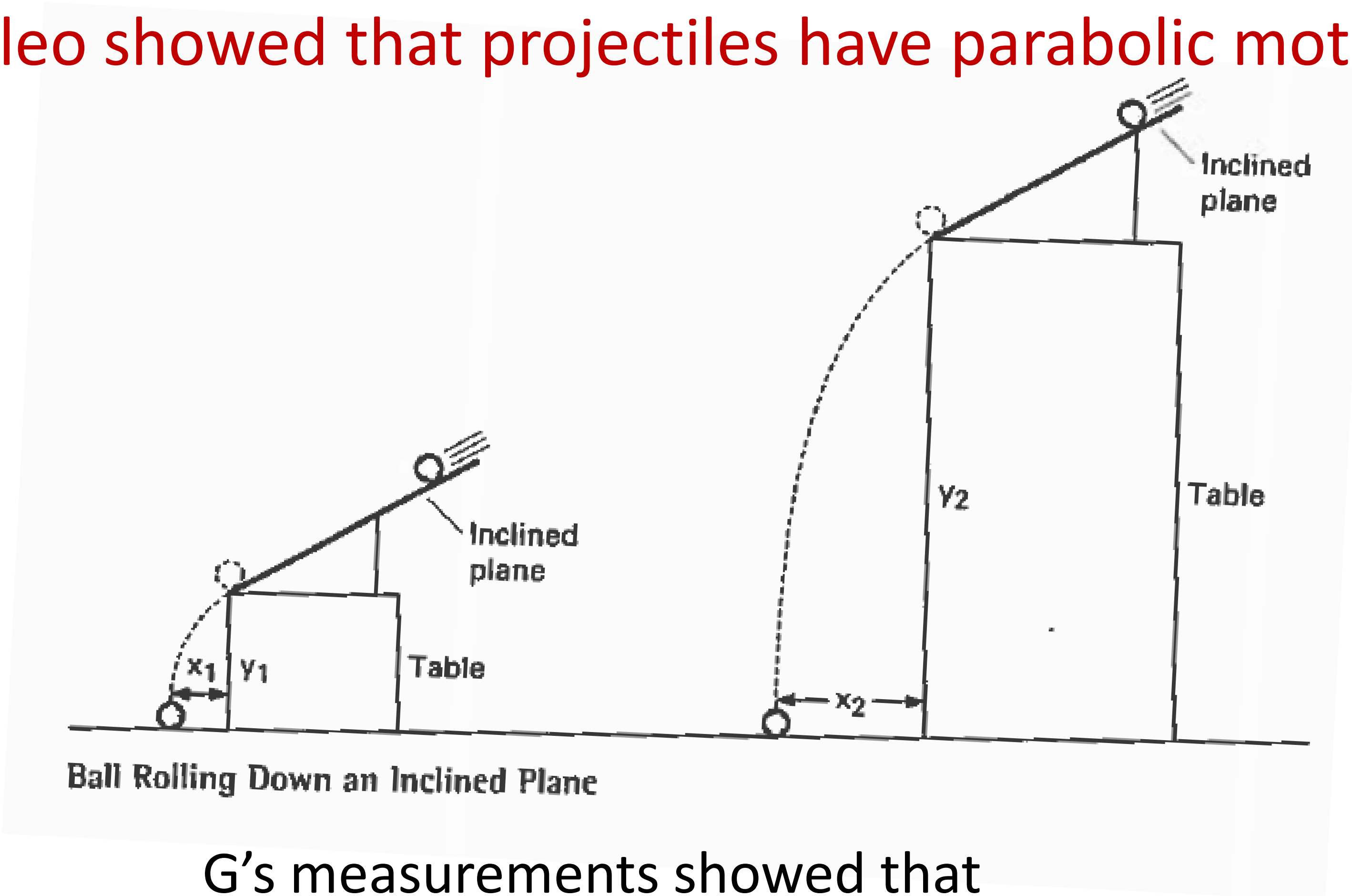
Total distance fallen: 1,1+3,1+3+5,1+3+5+7

= 1 : 4 : 9 : 16 in 1st 4 sec

He deduced $y=t^2$ (const. acceleration).



Galileo showed that projectiles have parabolic motion



G's measurements showed that

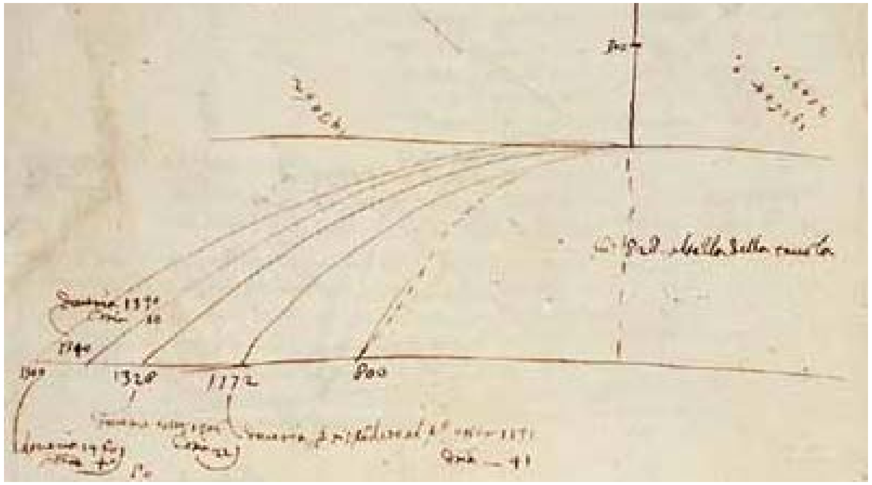
heights $y \propto x^2$

ranges $x \propto t$ (time in air)

(x = "range")

G analyzed motion in terms of composite ("double") motion
in both x and y simultaneously. Taken together, two observations imply $y \propto t^2$ as before

The actual logbook!



Galileo publishes a summary of his investigation of terrestrial motion in *Discourse on Two New Sciences* 1638 (published in Netherlands)

Importance of Galileo's approach to understanding motion: 1st combined use of empirical measurements and mathematical analysis for terrestrial motion of objects!

But: he also engaged in "thought experiments". For example, he couldn't measure actual falling body quantitatively, but deduced $y \propto t^2$ for falling body from his inclined plane results!